Human Thalamic Nucleus Mediating Taste and Multiple Other Sensations Related to Ingestive Behavior

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INTRODUCTION

Although the primate taste relay has been characterized by lesion (Blum et al. 1943; Burton and Benjamin 1971) and single cell recording studies (Burton and Benjamin 1971; Pritchard 1991; Pritchard et al. 1989), the sensations evoked by stimulation of this nucleus are unknown. We now report sensations evoked by threshold stimulation at microampere current levels (TMS) (Lenz et al. 1993) in the region of the human ventralis caudalis parvocellularis internis (Vcpci) that corresponds to the monkey thalamic taste relay (ventral posterior medial parvocellular nucleus, VPMpc) in anatomy, immunohistochemistry, and cytology (Hirai and Jones 1989). TMS in this region during awake neurosurgical procedures evoked contralateral special visceral/somatic (taste/pungent smell), general visceral (fullness of a hollow viscus), as well as painful (oral burning) and nonpainful general somatic sensations (oral and nasal tingling). General somatic/visceral sensation was evoked by stimulation at 80% of sites where special visceral/somatic sensation was evoked. Thus the primate thalamic taste relay may signal multiple sensations in addition to taste.

METHODS

We report results of the physiological exploration that preceded stereotactic thalamotomy under local anesthesia in three patients (designated A, B, and C). Targets predicted radiologically were corroborated physiologically by recording and stimulation (Lenz et al. 1993) with a glass-coated, platinum-iridium microelectrode (impedance 1–1.5 MΩ). Stimulation was delivered in trains of ~1-s duration at 300 Hz by using a waveform consisting of a 0.2-ms anodal pulse followed after 0.1 ms by a cathodal pulse of the same magnitude. In each of these patients a trajectory (Fig. 1, left) was made in the parasagittal plane containing cells responding to light touch stimulation of the tongue (tactile tongue representation). In two patients explorations were also made 2 mm medial to the tactile tongue representation (Fig. 1, A and B, right).

Physiological and psychophysical studies of sensation were carried out pre- and intraoperatively under a protocol reviewed and approved by the Joint Committee on Clinical Investigation of the Johns Hopkins University. All patients gave informed consent. Under this protocol patients were trained to use a questionnaire to identify sensations evoked by sensory stimuli (Lenz et al. 1994). All three patients accurately reported sensations evoked by somatic stimulation suggesting that they were reliable witnesses (Lenz et al. 1993, 1994). TMS-evoked sensations were assessed by the patient’s initial report, by the questionnaire, and by a forced choice of the primary taste sensations.

RESULTS

Figure 1 suggests that a circumscribed region mediates special visceral (taste at locations 1, 2, and 5) and special somatic sensations (pungent smell at locations 3 and 4; see DISCUSSION) and that this region corresponds to Vcpci (Schaltenbrand and Bailey 1959). At location 5 (Fig. 1C) a pure taste sensation (Table 1) was evoked at 5 μA, consistent with excitation of neural elements over a distance of <100 μm (Ranck 1975). Dorsal to this site, tingling sensations evoked by stimulation were referred to projected fields located on the face, and cells had tongue receptive fields (RFs). These findings indicate that the ventrocaudal (Vc) nucleus was dorsal to this site (Lenz et al. 1993). Ventral to this site, at the base of the thalamus (∧), TMS-evoked tingling in the hand indicating the dorsal border of the mediallemniscus (Lenz et al. 1993). In this case taste was evoked by stimulation in a discrete functional region below the tactile tongue representation. Overall, sites where TMS-evoked special visceral/somatic sensations were located are as follows: 1) over a 0.5–2 mm length of trajectory within 2 mm of the base of the thalamus (Fig. 1, A–C), 2) below the region where cells with cutaneous RFs were located (Fig. 1, B and C), and 3) either medial to (Fig. 1, A and B) or in the plane where cells had cutaneous RFs on tongue (Fig. 1C) or in the parasagittal plane where cells had cutaneous RFs in pharynx (Fig. 1B) (see Jones et al. 1986). Therefore the location of the discrete functional region where special visceral/somatic sensations were evoked seems to correspond to Vcpci (Fig. 1, A, top right).
Multiple other sensations were evoked by stimulation in Vcpci. General visceral and general somatic sensations were usually evoked at the same site (locations 1–4) as special visceral/somatic sensations. Sensations at all five locations were evoked by stimulation at currents <40 μA that produce excitation over distances of <200–500 μm from the stimulating electrode (Ranck 1975). TMS-evoked sensations were absent dorsal (Fig. 1, A and B) and ventral (Fig. 1B) to the level where special visceral/somatic sensations were evoked. Previously, TMS-evoked visceral sensations have only been reported by stimulation in nuclei distant from Vcpci (Lenz et al. 1994). When different categories of sensation were evoked at one site they were always evoked at the same current as in the case of sites in the region of Vc where thermal and paresthetic sensations were evoked by stimulation (Lenz et al. 1993). This data strongly suggests, but does not prove, that all the sensations evoked at locations 1–5 were due to stimulation of Vcpci.

**DISCUSSION**

This report demonstrates that Vcpci is the human thalamic taste relay nucleus corresponding to monkey VPMpc. Involvement of VPMpc in taste is based on lesion studies (Blum et al. 1943) and on recordings from cells responsive to gustatory stimuli (Benjamin 1963; Burton and Benjamin 1971; Pritchard et al. 1989). This is the first report of sensations evoked by stimulation in this region and strongly suggests that the primate thalamic taste relay mediates other modalities in addition to taste. These findings are consistent with evidence of convergent inputs to cells in VPMpc (Benjamin 1963; Pritchard et al. 1989) and to the dorsolateral segment of the nucleus of the solitary tract (NST) that projects to VPMpc (Beckstead et al. 1980; Beckstead and Norgren 1979).

The location and quality of sensations mediated by the primate thalamic taste relay are suggested by the present study. At location 2 a sour taste sensation was evoked in the posterior tongue ipsilaterally, suggesting that different tastes are topographically localized on the tongue. Perception of different tastes does vary as a function of position on the tongue.
TABLE 1. Descriptions of sensations evoked at locations 1–5

<table>
<thead>
<tr>
<th>Patient Initial (Letter)</th>
<th>Location—No. of Stimuli*</th>
<th>Threshold Current (in uA)</th>
<th>Description of Sensation</th>
</tr>
</thead>
<tbody>
<tr>
<td>SB (A)</td>
<td>1—7</td>
<td>20</td>
<td>Sour, ‘‘like licking a battery’’ and tingling of tongue and nose ‘‘up into middle of my head’’</td>
</tr>
<tr>
<td></td>
<td>2—5</td>
<td>20</td>
<td>Same as for site 1 but taste described at back of tongue ispsilateral to stimulation</td>
</tr>
<tr>
<td>MP (B)</td>
<td>3—7</td>
<td>40</td>
<td>Smell and sensation of black pepper in nose and ‘‘hot, burning’’ sensation in the mouth</td>
</tr>
<tr>
<td></td>
<td>4—6</td>
<td>40</td>
<td>Smell, ‘‘like vinegar’’ in the nose and ‘‘fullness in the throat’’</td>
</tr>
<tr>
<td>RK (C)</td>
<td>5—6</td>
<td>5</td>
<td>Metallic taste, acid in response to forced choice</td>
</tr>
</tbody>
</table>

Number of the location is indicated to the left of the dash; number of stimulus repeats is shown to the right.


Although VPMpc does not receive olfactory inputs, physiological and psychophysical studies suggest a trigeminal pathway accounting for TMS-evoked pungent smell (Tucker 1977). Studies in rats indicate that 80% of cells in the NST responding to gustatory stimuli also respond to pungent odorants (Van Buskirk and Ericksson 1977). The responses to odorants have patterns specific to the odorant and are abolished by dividing the ethmoidal branch of the trigeminal nerve. The significance of NST cellular odorant responses is suggested by psychophysical studies in three patients confirmed to be anosmic by olfactory evoked responses (Hummel et al. 1991). Two of three patients were able to distinguish qualitatively between different pungent odorants such as eugenol and acetic acid, which activate both cranial nerves V and I (Hummel et al. 1991). These results suggest that cells in human Vpcp may encode pungent odorants and that TMS-evoked pungent smell may result from excitation of these cells.

Significant convergence of sensory modalities is found in monkey VPMpc. In VPMpc two-thirds of cells responding to gustatory stimuli also respond to innocuous mechanical stimulation and one-half respond to thermal stimuli of the oral cavity (Pritchard et al. 1989). Evidence of convergence from general somatic, general visceral, and special visceral/somatic modalities is found in squirrel monkey VPMpc (Bloomquist et al. 1962; Burton and Benjamin 1971). Input to VPMpc arises from the lateral segment of the NST rostral to the point of entry of cranial nerve X (Beckstead et al. 1980). This rostrolateral segment of NST receives inputs from cranial nerves V, VII, IX, and X (Beckstead and Nor- gren 1979). Thus studies of afferent connections and neuronal activity suggest that input of special visceral (cranial nerves VII and IX), special somatic (V), general visceral (X), and general somatic sensation (V) are mediated by VPMpc via input from the rostrolateral segment of the NST (Beckstead et al. 1980).

General visceral or general somatic sensations were evoked at 80% of sites where special visceral/somatic sensations were evoked. The sensation of fullness of a hollow organ (throat, location 4) was classified as a general visceral sensation. Therefore general visceral sensations in cranial nerve X territory and noxious oral (location 3) or innocuous nasal cranial nerve V somatic sensations (locations 1 and 2) were evoked at the same locations as special visceral/somatic sensations. The present report argues forcefully that, in primates, the rostrolateral segment of the NST and the thalamic taste relay nucleus mediate multiple sensations in addition to taste.

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